#### PAPER • OPEN ACCESS

# Calorimetric system for high-precision determination of activity of the <sup>51</sup>Cr neutrino source in the BEST experiment

To cite this article: E P Veretenkin et al 2017 J. Phys.: Conf. Ser. 798 012140

View the article online for updates and enhancements.

### You may also like

- <u>The Nucleosynthetic Yields of Core-</u> collapse Supernovae: Prospects for the Next Generation of Gamma-Ray <u>Astronomy</u> S. Andrews, C. Fryer, W. Even et al.
- <u>Reevaluation of thermonuclear reaction</u> rate of <sup>50</sup>Fe(p. )<sup>51</sup>Co Li-Ping Zhang, , Jian-Jun He et al.
- <u>Lower Limits on the Nucleosynthesis of</u> <sup>44</sup>Ti and <sup>60</sup>Fe in the Dynamic Spiral-arm <u>Cosmic-Ray Propagation Model</u> David Benyamin and Nir J. Shaviv





DISCOVER how sustainability intersects with electrochemistry & solid state science research



This content was downloaded from IP address 3.133.149.168 on 11/05/2024 at 09:00

## Calorimetric system for high-precision determination of activity of the <sup>51</sup>Cr neutrino source in the BEST experiment

#### E P Veretenkin<sup>1</sup>, V N Gavrin<sup>1</sup>, S N Danshin<sup>1</sup>, T V Ibragimova<sup>1</sup>, A A Kalashnikova<sup>2</sup>, J P Kozlova<sup>1,\*</sup> and A A Martynov<sup>1</sup>

<sup>1</sup>Institute for Nuclear Research, Russian Academy of Sciences, pr. Shestidesyatiletiya Oktyabrya 7a, Moscow, 117312 Russia

<sup>2</sup>Bauman Moscow State University, ul. Baumanskaya 2-ya, 5, Moscow, Russia

E-mail: <sup>\*</sup>julia@inr.ru

Abstract. The calorimetric system based on mass-flow calorimeter for high-precision determination of neutrino flux from <sup>51</sup>Cr source with activity 3MCi and higher is created for experiment BEST. The achieved heat release uncertainties are less than 0.25% in the whole range of the heat power and less than 0.1% in the range of 250-500 W. Total value the uncertainty considering the uncertainty of the energy release in the  ${}^{51}$ Cr decay (0.23%) shows that the activity of 3MCi <sup>51</sup>Cr neutrino source can be determined with accuracy better than 0.5%.

#### 1. Introduction

For the first time intense artificial neutrino sources were employed by SAGE and GALLEX in order to test fully all of the experimental procedures used in their solar neutrino measurements. SAGE used <sup>51</sup>Cr [1] and <sup>37</sup>Ar [2] sources and GALLEX twice used a <sup>51</sup>Cr source [3, 4]. The weighted-average result of these experiments, expressed as the ratio R of the measured neutrino capture rate to the expected rate, based on the known neutrino capture cross section gave  $R = 0.87 \pm 0.5$ , more than two standard deviations less than unity, named the Gallium anomaly [5]. The Gallium anomaly can be explained as v<sub>e</sub> oscillations into sterile states at very short baselines with  $\Delta m^2$  about 1 eV<sup>2</sup> [6]. For solution of this problem the experiment BEST has been proposed [7]. One of the tasks of this experiment is creation of the calorimetric system for high precision measurement of the activity of a more than 3 MCi <sup>51</sup>Cr source. This source will have the initial thermal power about 650 W [8]. For comparison, heat release of used in the experiment SAGE  ${}^{51}$ Cr source is about ~ 90 W that was measured by the calorimetric method with accuracy of 1.2% [1].

Additionally to the calorimetric method in the BEST project the source activity will be determined with accuracy of 1% by measurement its gamma-rays using a Ge semi-conductor detector [9].

### 2. Mass-flow calorimetric system

<sup>51</sup>Cr decays by electron capture to the ground state of the <sup>51</sup>V (90%) and to the excited state of the <sup>51</sup>V<sub>m</sub> (10%), which then decays to the ground state, emitting a 320 keV gamma ray. The gamma-ray absorption makes a main contribution into the source heat release that can be measured by calorimetric system. The total energy release with <sup>51</sup>Cr decay is presented in table 1 considering a new data of <sup>51</sup>Cr decay characteristics [10].

The average energy release is  $36.750 \pm 0.084$  keV/decay with the uncertainty 0.23%. So, we should measure the heat release with the same accuracy and therefore the accuracy of the source activity determination will be about 0.5%.

Table 1. The total energy release with Cr-51 decay.			
Type of energy release	Energy, keV	Contribution to <sup>51</sup> Cr	Energy release with
		decay	<sup>51</sup> Cr decay, keV
Gamma rays	320.0835 (4)	0.0991 (2)	31.720 (64)
K-capture	5.465	0.8919 (17)	4.874 (9)
L-capture	0.628	0.0927 (14)	0.0582 (9)
M-capture	0.067	0.0154	0.001
inner bremsstrahlung	751 (max)	3.8×10 <sup>-4</sup> ×0.902 (±10%)	0.096 (10)
inner bremsstrahlung	430 (max)	$1.2 \times 10^{-4} \times 0.0983 (\pm 10\%)$	0.001
Total			36.750 (84)
TOTAL			0.23%



Figure 1. Hydraulic circuit of the mass flow calorimeter.

As it is necessary to measure the heat release of hundreds watts, the mass flow calorimeter, which provides the removal of such a significant amount of heat, was chosen. The measuring principle of this calorimeter is based on the removal of all heat release by the coolant. In this case the heat release is proportional to the difference between the output and input temperatures of the coolant, according to the equation:

$$N = k \times Q \times (T_{out} - T_{in}), \tag{2}$$

where

N – heat release of the source, W.

k - the proportionality factor, which is the specific heat capacity of the coolant at the constant its flow rate and in the absence of heat losses in the colorimeter system, J/ (kg  $\cdot$  K).

 ${\bf Q}$  - the coolant flow rate, kg/s.

 $T_{\mbox{\scriptsize out}}-$  the temperature at the outlet of the heat exchanger, K.

 $T_{in}$  - the temperature at the inlet to the heat exchanger, K.

The calorimeter system design is shown at figure 1. The neutrino source (b) is placed in a container (f) of the measuring cell 1 and surrounded by the labyrinth heat exchanger (e), thermal insulation (a) and biological shield (c). The coolant input and output temperatures are measured by the platinum thermistors 1 (g) and (d) with the uncertainty 0.002 K, respectively. A precision gear pump 5 provides a constant flow of the coolant through the heat exchanger that is measured by the Corioles flow meter ( $\pm 0.05\%$ ) 2. To maintain a constant input temperature, the cooling thermostat ( $\pm 0.01$  K) 3 is used. Bypass line 4 and temperature damper 6 are used for precise thermostating.

At first the prototype of the calorimetric system was created. It was calibrated by using an electrical heating imitator. The deionized water was used as a coolant for calibration of the prototype calorimeter. The electric power measurement scheme is presented at figure 2. DC power supply was used for electric heating. The voltages on the heat simulator and the shunt were measured by two-channel digital multimeter (0.01 V). The electric power uncertainty (0.03%) is determined by the accuracy of the shunt resistance (R=  $52.14 \pm 0.01$  Ohm at 20 °C).



Figure 2. Circuit of the electric power measurements.

The calibration data for prototype of the calorimeter are placed at figure 3. The calibration points have a linear dependence: N (dT) =  $(69.677 \pm 0.079) \times dT + (0.62 \pm 0.36)$ , and the coefficient of determination is close to unity: R<sup>2</sup> = 0.99998. The specific heat capacity of deionized water, calculated from this dependence, is 4180.6 ± 2.3 J/kg·K, that is very close to the reference data (c<sub>p</sub> = 4180.2 J/kg·K [11]). This fact points out to the correctness of all measurements and that the calorimetric system heat losses are very low.



**Figure 3.** Calibration data of the prototype calorimeter ( $\bullet$  – the measured points, uncertainties - in the range of experimental points, solid line – linear approximation).

The uncertainty of the heat release determinations of the calorimetric system prototype is less than 0.5% in the range of the heat power 120-700 W and less than 0.25% in the range of 270-700 W.

The obtained data and experience allowed to design and make the calorimeter with required parameters for the BEST experiment. The calorimeter consists of the biological shield from tungsten with thickness 30 mm and a new measuring cell (Figure 4).



Figure 4. The measuring cell of the calorimetric system.

The measuring cell has got advanced thermal insulation made from the foil-coated foamed polypropylene and foamed polyurethane. As a coolant, the composition of the deionized water and ethanol is used. A new heat simulator with the same geometric configuration and thermal characteristics (heat conduction and heat capacity) as a neutrino source was created.

Special software based on LabVIEW Package was designed. The software ensures reading and storing the data of mass flow rate, density, total mass and temperature of the coolant through the flow meter; the input and output temperatures of coolant through the heat simulator; and electric power on the heat simulator. Processing data of the coolant mass flow, the input and output temperatures and their difference are displayed as the time graphs.

The calibration data of the calorimeter system are shown at figure 5.

The calibration points correspond to linear dependence:  $N = (49.57 \pm 0.03) \times dT + (0.93 \pm 0.20)$ , but the uncertainties values are about half the values of the uncertainties of measurements with the calorimeter prototype. The obtained uncertainties of the heat release are considerably less than the same data for the calorimeter prototype: less than 0.35% in the range of 100-500 W and less than 0.15% in the range of 250-500 W.

#### 3. Conclusions

The calorimetric system for neutrino source activity measurement to the BEST experiment is created and checked. Considering the known 0.23% uncertainty in energy release in <sup>51</sup>Cr decay with the uncertainty obtained in the heat release measurements, the neutrino flux in the experiment BEST can be determined with accuracy of ~ 0.5%



**Figure 5.** Calibration data of the calorimeter system ( $\bullet$  – the measured points, uncertainties - in the range of experimental points, solid line – linear approximation).

#### Acknowledgments

The reported study was funded by RFBR according to the research project № 16-02-00800.

#### References

- [1] SAGE Collaboration 1999 Phys. Rev. C 59(4) 2246
- [2] SAGE Collaboration 2006 Phys. Rev. C 73 045805
- [3] Gallex Collaboration 1995 Phys. Lett. B 342 440
- [4] Gallex Collaboration 1998 Phys. Lett. B 420 114
- [5] Giunti C 2007 Mod. Phys. Lett. A 22 2499
- [6] Gariazzo S *et al.* 2015 *arXiv*:1507.08204
- [7] Gavrin V et al. 2010 arXiv:1006.2103
- [8] Veretenkin E P et al. 2015 Physics of Atomic Nuclei **78**(14) 1606
- [9] Gorbachev V V et al. 2015 Physics of Atomic Nuclei 78(14) 1617
- [10] Chechev V P and Kuzmenko N K 2004 *Table de radionucléides* <sup>51</sup>Cr **1** (Sevres cedex: BIPM)
- [11] Wagner W and Pruß A 2002 J. Phys. Chem. Ref. Data 31 387